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A VERSATILE LINEAR GRIDDED-TUBE CAVITY UHF POWER AMPLIFIER

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EIMAC

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13. ABSTRACT A linear UHF broad-band power amplifier, utilizing a type X2135J focused-beam power triode with a double-tubed anode resonator, was designed, built and tested. The X2135J development model was similar to the type 8938 triode but was modified for higher thermal & electrical conductivity.

The tube-cavity combination gave 1200 watts of CW output over a minimum instantaeous bandwidth of 11.17 MHz, with 11 to 12 db of gain. The plate efficiency was 54 percent; the amplifier was mechanically tuneable over a 225 to 400 MHz band. Pulse tests were made with more than 12.5 KW output, with 10 percent duty and 10 millisecond pulse width. Pulse power gain was 11.2 to 12.3 db at the 11.3 MHz bandwidth. Linearity (intermodulation distortion) measured by the two-tone method were degraded 10 db at 400 MHz compared to low frequency (2 MHz) results; further effort would be required to assign a cause and improve linearity at UHF frequencies.

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Tuneable						
Kilowatt						
Pulse						
CW						
UHF						
Linear						

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FINAL REPORT

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by

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R. I. Sutherland
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TABLE OF CONTENTS

ABSTRACT

A linear UHF broad-band power amplifier, utilizing a type X2135J focused-beam power triode with a double-tuned anode resonator, was designed, built and tested. The X2135J development model was similar to the type 8938 triode but was modified for higher thermal and electrical conductivity.

The tube-cavity combination gave 1200 watts of CW output over a minimum instantaneous bandwidth of 11.17 MHz, with 11 to 12 db of gain. The plate efficiency was 54 percent; the amplifier was mechanically tuneable over a 225 to 400 MHz band. Pulse tests were made with more than 12.5 KW output, with 10 percent duty and 10 millisecond pulse width. Pulse power gain was 11.2 to 12.3 db at the 11.3 MHz bandwidth. Linearity (intermodulation distortion) measured by the two-tone method were degraded 10 db at 400 MHz compared to low frequency (2 MHz) results; further effort would be required to assign a cause and improve linearity at UHF frequencies.

CIRCUIT DESIGN

In order to meet the design objectives for the bandwidth and frequency range a double-tuned plate resonator circuit is used. The primary circuit is connected to the tube and the secondary circuit is connected to the load. The primary circuit is a transmission line segment shorter than a quarter wavelength at the frequency of operation. The characteristic impedance of this line was chosen for the best compromise between bandwidth and a practical physical length. In general, for a quarter wavelength cavity structure, the higher the characteristic impedance, the greater the bandwidth. A high characteristic impedance transmission line has less distributed capacitance therefore, less stored energy yielding greater bandwidth.

This can be seen by inspecting the following equations:

$$Zo = \frac{L}{C}$$

$$E = \frac{CV^2}{2} \qquad \text{(See Reference \#1 and \#2)}$$

where Zo = characteristic of the coaxial transmission line

L = inductance per unit length of transmission line

C = capacitance per unit length of transmission line

E = stored energy per unit length at transmission line

V = potential difference across the transmission line capacitance

For a given inductance per unit length of transmission line, the lower the capacitance in the same length, the higher the characteristic impedance of the transmission line. Also, the lower capacitance per unit length means lower stored energy and therefore greater bandwidth.

All coaxial transmission line tuned circuits reduce the bandwidth attainable from a standard LC circuit by a calculable amount. The circuit designer must make compromises between bandwidth and the physical length.

The equations:

$$X_L = Zo\tan \theta°$$

At resonance $X_L = X_C \qquad X_C = Zo\tan \theta°$

where: X_L = Inductive reactance of line the segment

X_C = Capacitive reactance of the tube loading the line

Zo = Characteristic impedance of the transmission line segment

$\theta°$ = Length transmission line in electrical degrees

are used to determine the physical size of the tuned circuit. It can be seen that while a high Zo is advantageous from a bandwidth point of view, it is not necessarily so for convenient physical size. The tuned circuit must have sufficient size to provide tuning and output power coupling arrangements.

The secondary, of the double-tuned circuit, is again a transmission line segment loaded with a variable capacitance. The length of the line segment is variable, and less than a quarter wavelength long. Capacitive coupling is used between primary and secondary circuits. By adjusting the line length, the variable capacitor and the coupling controls, it is possible to vary the L to C ratio and loading to provide the proper plate load resistance for the tube and the desired bandwidth.

The data tabulated in Figure 1 provides a summary of possible choices of characteristic impedances for the plate circuit resonator. There are three major considerations when making the choice. They are:

1. Are the tubing sizes required commercially obtainable?
2. Does the design yield a physically attainable cavity length and diameter?
3. Is the design providing the maximum bandwidth that is practical?

Other considerations do enter into the choice such as; ease of providing for adequate cooling by conduction and forced air; ease of making tuning and loading adjustments, and ease in manufacturing of the final design.

The characteristic impedance of 46.34 ohms has been chosen as the most promising approach. It is most difficult to get the required bandwidth at the 225 MHz end of the band. Figure 1 indicates that the 46.34 ohm line segment gives a 25 percent bandwidth reduction at 225 MHz and a 10 percent reduction at 400 MHz. A 50 ohm line segment would be better for the bandwidth requirement, but the physical length of the cavity is prohibitively short. In order to allow for this bandwidth reduction, the tube plate load resistance was chosen to provide fifteen megahertz bandwidth to the -1 dB points. The available bandwidth at the output port is then eleven megahertz at 225 MHz.

An overcoupled double-tuned circuit with a -0.25 dB ripple was chosen. This type of a circuit has a very good phase response and has been used quite successfully in the television broadcast industry. To determine the operating plate load resistance for the tube, the following equation was used:

$$R = \frac{0.138}{C(BW)}$$

where R = 8938 plate load resistance

C = 8938 output capacitance plus any stray capacitance

BW = bandwidth to the -1.0 Db points

The plate load resistance was calculated with the above equation using 15 MHz as the required bandwidth as previously explained. The above equation is from the book titled "Television Principles" by R. B. Dome. Several other equations appear in this reference for completing the design of the double-tuned circuit. Figure 2 shows what the tube must be capable of doing to provide 15 MHz bandwidth at 225 MHz and at a power output of 1250 watts at the center of the band. Figure 3 shows the same requirements for a frequency of 400 MHz. While the bandwidth is more difficult to attain at 225 MHz than 400 MHz the efficiency is more difficult at 400 MHz.

After determining what the tube must do to meet the objective

```
WHAT IS THE FREQUENCY OF OPERATION (MHZ)? 400
WHAT IS THE TUBE OUTPUT CAPACITANCE (PFD)? 13
WHAT IS THE TUNING CAPACITANCE AT THE TUBE END (PFD)? 1
HOW MANY ZO CALCULATIONS ARE YOU GOING TO TRY? 4
WHAT ARE THE ZO VALUES? 32.58,39.85,46.34,50

 ZO            LENGTH-INCHES  %BW OF LC    B/A RATIO    H/D RATIO

 32.58          3.37           82           1.72         1.60

 39.85          2.91           87           1.94         1.80

 46.34          2.59           90           2.16         2.01

 50.00          2.43           91           2.30         2.13

DO YOU WANT B/A AND H/D RATIOS EXPLAINED? YES
B/A IS RATIO OF INNER DIA. OF OUTER CONDUCTOR TODIA. OF INNER CONDUCTOR.
H/D IS RATIO OF LENGTH OF WALL OF SQUARE BOX TO DIA. OF CENTER CONDUCTOR
DO YOU WANT TO GIVE IT ANOTHER GO? YES


WHAT IS THE FREQUENCY OF OPERATION (MHZ)? 225
WHAT IS THE TUBE OUTPUT CAPACITANCE (PFD)? 13
WHAT IS THE TUNING CAPACITANCE AT THE TUBE END (PFD)? 1
HOW MANY ZO CALCULATIONS ARE YOU GOING TO TRY? 4
WHAT ARE THE ZO VALUES? 32.58,39.85,46.34,50

 ZO            LENGTH-INCHES  %BW OF LC    B/A RATIO    H/D RATIO

 32.58          8.34           63           1.72         1.60

 39.85          7.54           70           1.94         1.80

 46.34          6.92           75           2.16         2.01

 50.00          6.61           77           2.30         2.13

DO YOU WANT B/A AND H/D RATIOS EXPLAINED? NO
DO YOU WANT TO GIVE IT ANOTHER GO? NO

>
```

FIGURE 1

```
TWO ELEMENT CHEBYSHEV OR TYPE C RESPONSE.
PEAK TO VALLEY RIPPLE -0.25 DB


WHAT IS THE TUBE OUTPUT CAPACITANCE(PFD)? 13
WHAT VALUE OF PRIMARY TUNING CAPACITANCE (PFD)? 1
WHAT IS THE FREQUENCY OF OPERATION (MHZ)? 225
WHAT IS THE TRANSMISSION LINE ZO (OHMS)? 50
WHAT IS THE DESIRED 1 DB BANDWIDTH(MHZ)? 15
WHAT IS THE POWER OUTPUT (WATTS)? 1250
WHAT IS THE CIRCUIT EFFICIENCY (%)? 83.7


FO(MHZ): 225
1 DB BANDWIDTH(MHZ): 15
PLATE LOAD RESISTANCE(OHMS): 657.14286
COEFFICIENT OF COUPLING: 9.4333333E-02
PRIMARY TO SECONDARY Q RATIO: 1.4982059
PRIMARY Q: 13.006194
SECONDARY Q: 8.6811787
PRIMARY INDUCTANCE(HENRIES): 3.5729101E-08
SECONDARY INDUCTANCE(HENRIES): 3.0666667E-07
SECONDARY SERIES CAPACITANCE (PFD): 1.6296296E-12
PEAK PLATE VOLTAGE SWING(VOLTS): 1401.2085
PEAK FUNDAMENTAL PLATE CURRENT (AMPS): 2.1322738
PEAK PLATE CURRENT (AMPS): 4.2645476
DC PLATE CURRENT (AMPERES): 1.3574477

>
```

FIGURE 2

```
TWO ELEMENT CHEBYSHEV OR TYPE C RESPONSE.
PEAK TO VALLEY RIPPLE -0.25 DB


WHAT IS THE TUBE OUTPUT CAPACITANCE(PFD)? 13
WHAT VALUE OF PRIMARY TUNING CAPACITANCE (PFD)? 1
WHAT IS THE FREQUENCY OF OPERATION (MHZ)? 400
WHAT IS THE TRANSMISSION LINE ZO (OHMS)? 50
WHAT IS THE DESIRED 1 DB BANDWIDTH(MHZ)? 12.36
WHAT IS THE POWER OUTPUT (WATTS)? 1250
WHAT IS THE CIRCUIT EFFICIENCY (%)? 83.7


FO(MHZ): 400
1 DB BANDWIDTH(MHZ): 12.36
PLATE LOAD RESISTANCE(OHMS): 797.50347
COEFFICIENT OF COUPLING: 4.37235E-02
PRIMARY TO SECONDARY Q RATIO: 1.4982059
PRIMARY Q: 28.060828
SECONDARY Q: 18.72962
PRIMARY INDUCTANCE(HENRIES): 1.1304911E-08
SECONDARY INDUCTANCE(HENRIES): 3.7216828E-07
SECONDARY SERIES CAPACITANCE (PFD): 4.24875E-13
PEAK PLATE VOLTAGE SWING(VOLTS): 1543.6156
PEAK FUNDAMENTAL PLATE CURRENT (AMPS): 1.9355597
PEAK PLATE CURRENT (AMPS): 3.8711194
DC PLATE CURRENT (AMPERES): 1.2322156

>
```

FIGURE 3

specification, an operating line was plotted on a set of constant current lines for the tube chosen to do the job. Figure 4 shows such an operating line for the 8938. Figure 5 tabulates the results of a Fourier analysis of the plate and grid current pulses using the EIMAC Application Bulletin Five tube performance computer. The data in Figure 5 is for the tube only. The circuit efficiencies must still be taken into account to obtain the expected power output, total efficiency and gain.

Figure 6 is a sketch of the expected voltage response across the 50 ohm load as a function of frequency. The load presented to the tube by the plate resonant circuits is a pure resistance at only one point. At the very center of the response curve the operating line as plotted on a set of constant plate current lines is a straight line. All other operating lines within the passband are elliptical. An elliptical operating line implies that the plate load presented to the tube consists of resistance and a reactance. At the band edges the effect is the most pronounced. In a single tuned circuit operated at 3 dB down the side of the response curve, the resistance and reactive components are equal. Two main effects become apparent. First, in order to get the same power output, the plate voltage would have to be raised 1.41 times. Second, the tube plate load impedance becomes greater causing the plate current to decrease, and in the case of a tetrode, the screen current would increase perhaps to the point where the screen dissipation rating would be exceeded. Prolonged operation under these conditions could cause a catastrophic tube failure. The choice of a double-tuned circuit operating over a bandwidth between the -1.0 dB points greatly minimizes the problem of off resonance operation. In fact, according to the work prepared by Parker [3] and confirmed by actual experience, a two element Chebyshev network with a peak-to-valley ripple of 0.25 dB can be operated at the edge of the passband with no more than a 10 percent voltage overswing ratio $\left(\frac{|Z|}{R}\right)$.

PULSE OPERATION

The two most severe pulse operation requirements outlined in Table 1, design objectives, are:

1. 0.10 duty @ 10.0 msec pulse width
2. 0.0625 duty @ 3.0 msec pulse width

TABLE 1

DESIGN OBJECTIVES FOR VERSATILE LINEAR GRIDDED-TUBE CAVITY UHF AMPLIFIER DEVELOPMENT

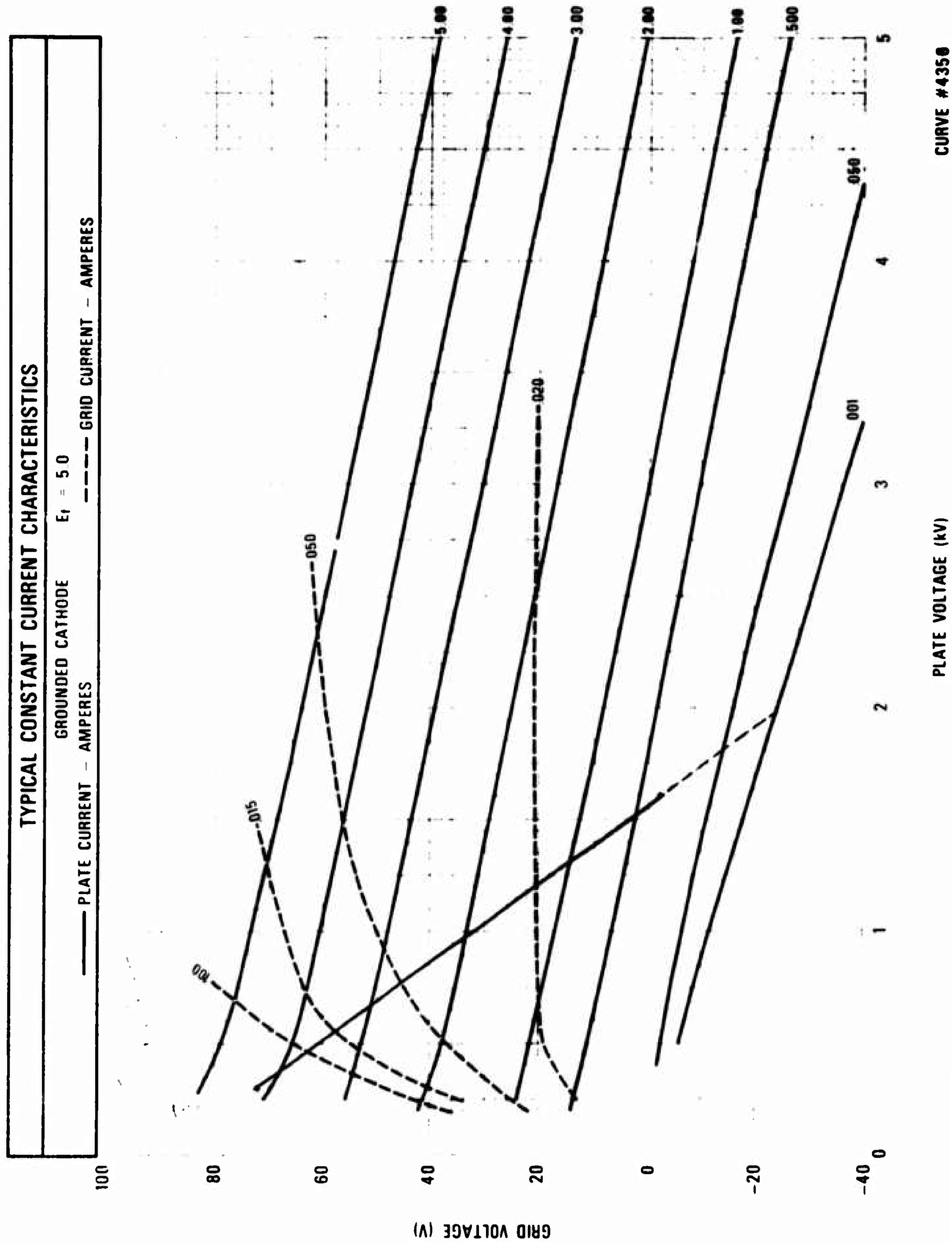
+Frequency Range of Operation	225-400 MHz
+Power Output (Average) ± 1.0 dB over range of oprn.	1.25 KW
Instantaneous Bandwidth	+11.0MHz*& 20.0 MHz
+Power Gain (11.0 MHz Handwidth)	13.0 dB
+Band-Pass Ripple (Both bandwidth conditions)	1.0 dB
+Intermodulation Distortion (2-tone)	-35 dB
Harmonic Output Power	-40 dB
+Phase Linearity (11.0 MHz Bandwidth)	±5.0 degs.
Pulse Handling Capability (pulse-width)	(min) 500 μsec (max) 12.0 msec
Duty Cycle (tentative)	0.25 @ 12.0 msec width 0.25 @ 500 μsec width 0.10 @ 10.0 msec width 0.125 @ 6.0 msec width 0.0625 @ 3.0 msec width
Efficiency (11.0 MHz Bandwidth)	(min) 55 %
Maximum Load VSWR	1.5
Input and Output Impedance	(both) 50 Ohms
Intrinsic Power Droop During Pulse (all conditions)	0.2 dB
Intrinsic Phase Variation or Droop	TBS
Cooling (Tube and Cavity)	Forced Air**
Assembly size and weight	TBS

*Bandwidth as measured ±5.5 MHz about center of Frequency of Operation

**Forced air cooling for shipboard and airborne under pressurized conditions

TBS - To be specified at preliminary design review

+ Major Design Objectives



TYPICAL CONSTANT CURRENT CHARACTERISTICS
GROUNDED CATHODE
E_f = 5.0
PLATE CURRENT – AMPERES
GRID CURRENT – AMPERES
5.00
4.00
3.00
2.00
1.00
.500
.050
.001
.020
.050
.015
.100
100
80
60
40
20
0
-20
-40
0
1
2
3
4
5
GRID VOLTAGE (V)
PLATE VOLTAGE (kV)
CURVE #4358

FIGURE 4

```
GROUNDED GRID TRIODE PERFORMANCE.
EIMAC APPLICATION BULLETIN 5 PROCEDURE.

TUBE TYPE? 8938
CURVE NUMBER? 4356
DATE? OCTOBER 29 1974

PLATE-TO-G1 VOLTAGE=? 1600
DC BIAS VOLTAGE (NO-)=? 2
EB MIN VOLTAGE=? 300
EKM VOLTAGE=? 74

PLATE CURRENT POINTS.
A=? 4.25
B=? 4.15
C=? 3.75
D=? 2.95
E=? 2.10
F=? 1.15
G=? 0.30

GRID CURRENT POINTS.
A=? 0.25
B=? 0.16
C=? 0.09
D=? 0.06
E=? 0.035
F=? 0.017
G=? 0

DC PLATE CURRENT= 1.3770833 AMPERES
PEAK FUNDAMENTAL PLATE CURRENT= 2.1337083 AMPERES
POWER INPUT= 2203.3333 WATTS
POWER OUTPUT= 1386.9104 WATTS  ...  1160W Amp. output (Useful)
PLATE DISSIPATION= 895.37012 WATTS
PLATE LOAD RESISTANCE= 609.2679 OHMS
EFFICIENCY= 62.94601 PERCENT   ...  52.69% Amp. eff.
DC GRID CURRENT= 4.0583333E-02 AMPERES
PEAK FUNDAMENTAL GRID CURRENT= 7.0245E-02 AMPERES
DRIVE POWER= 81.546273 WATTS
INPUT IMPEDANCE= 33.576029 OHMS
GRID DISSIPATION= 2.52882 WATTS
POWER GAIN= 17.007649X OR  12.306443 DECIBELS...11.54 db Amp. gain

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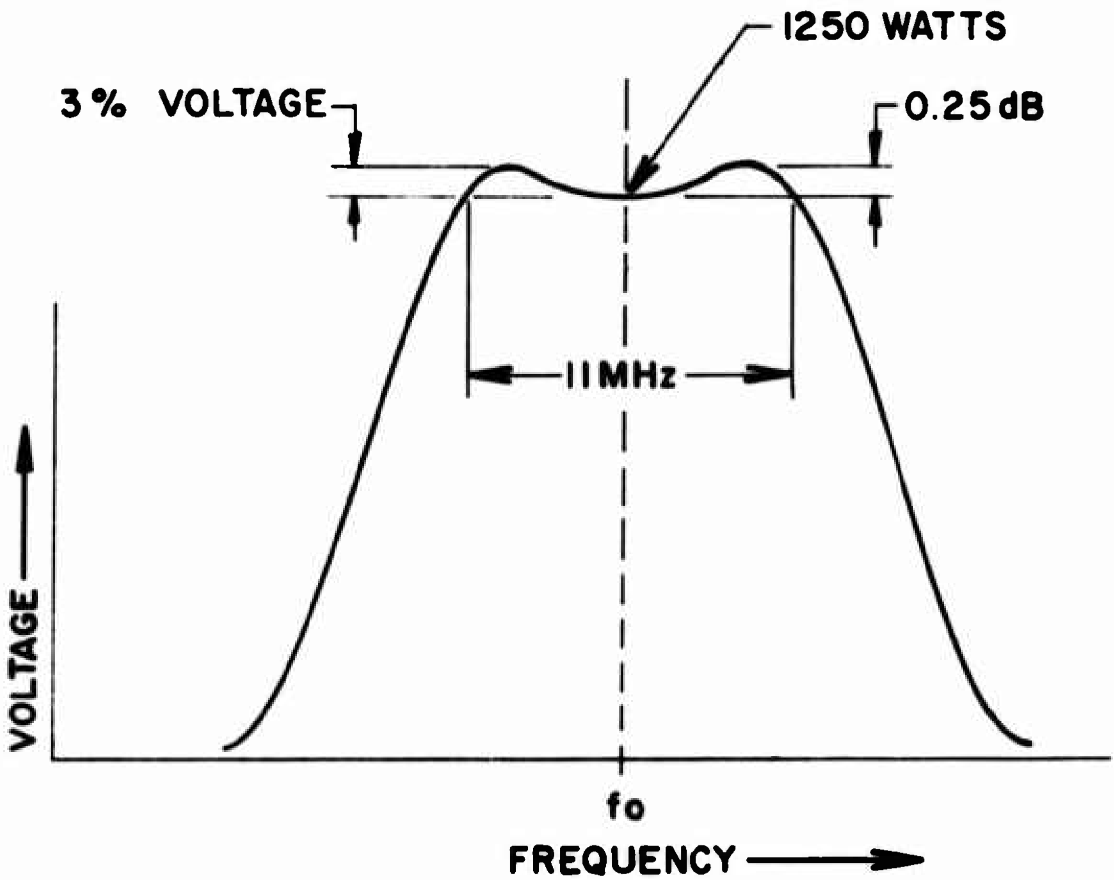
FIGURE 5



AMPLIFIER BAND - PASS CHARACTERISTIC

FIG. 6

The first requirement above represents a pulse power of 12,500 watts for an average putput power of 1250 watts. The second requirement is for 20,000 watts during the pulse for an average output power of 1250 watts.

Figure 7 tabulates the results of an 8938 operating line (Fig. 8) capable of meeting the specified 12,500 watts output power and bandwidth during the pulse. These data show what the tube must do. The efficiency of the anode tuned circuits must still be taken into consideration.

Figure 9 is a tabulation of the calculations based on the 8938 operating line of Figure 10 which will deliver 20,000 watts output power at the required bandwidth during the pulse. Here again the efficiency of the anode circuit must be taken into account to arrive at the estimated output power, gain and efficiency.

AMPLIFIER PERFORMANCE SUMMARY

Figure 11 provides a summary of calculated amplifier performance characteristics.

```
GROUNDED GRID TRIODE PERFORMANCE.
EIMAC APPLICATION BULLETIN 5 PROCEDURE.

TUBE TYPE? 8938
CURVE NUMBER? 4435
DATE? OCTOBER 29 1974

PLATE-TO-G1 VOLTAGE=? 4900
DC BIAS VOLTAGE (NO-)=? 58
EB MIN VOLTAGE=? 500
EKM VOLTAGE=? 228

PLATE CURRENT POINTS.
A=? 15.0
B=? 14.5
C=? 13.0
D=? 9.8
E=? 5.5
F=? 1.7
G=? 0.001

GRID CURRENT POINTS.
A=? 1.10
B=? 0.50
C=? 0
D=? 0.026
E=? 0.024
F=? 0
G=? 0

DC PLATE CURRENT= 4.3334167 AMPERES
PEAK FUNDAMENTAL PLATE CURRENT= 7.13975 AMPERES
POWER INPUT= 21233.742 WATTS
POWER OUTPUT= 15707.45 WATTS ... 13,146W Amp.output (Useful)
PLATE DISSIPATION= 6340.2232 WATTS
PLATE LOAD RESISTANCE= 616.26808 OHMS
EFFICIENCY= 73.974009 PERCENT     ...     61.92% Amp. eff.
DC GRID CURRENT= 9.1666667E-02 AMPERES
PEAK FUNDAMENTAL GRID CURRENT= .17713833 AMPERES
DRIVE POWER= 834.12527 WATTS
INPUT IMPEDANCE= 31.160787 OHMS
GRID DISSIPATION= 15.056758 WATTS
POWER GAIN= 18.831044X OR  12.748744 DECIBELS ...11.98 db Amp.gain.

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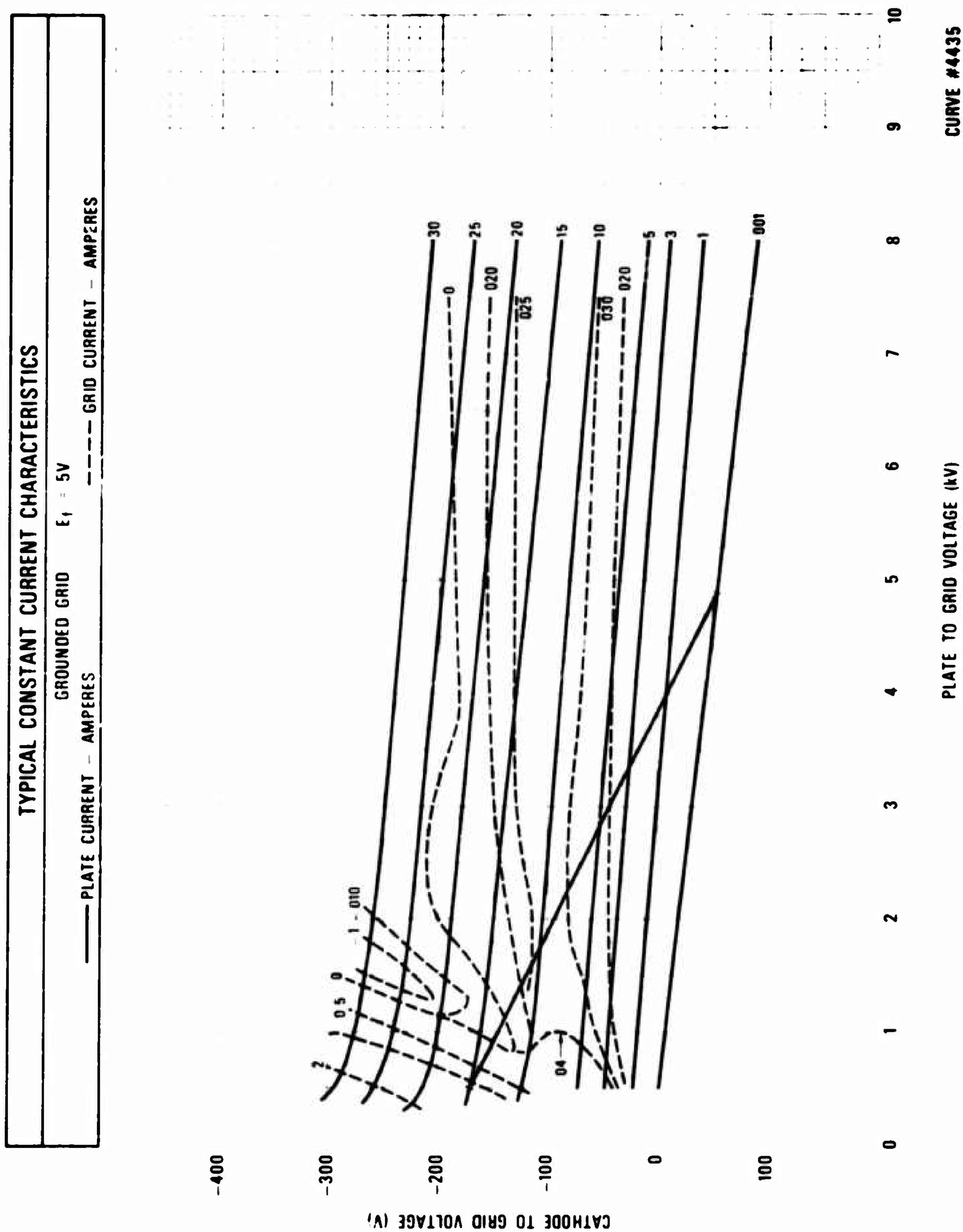
FIGURE 7



TYPICAL CONSTANT CURRENT CHARACTERISTICS
GROUNDED GRID
E_f = 5V
PLATE CURRENT - AMPERES
GRID CURRENT - AMPERES
CATHODE TO GRID VOLTAGE (V)
PLATE TO GRID VOLTAGE (kV)
CURVE #4435

FIGURE 8

```
GROUNDED GRID TRIODE PERFORMANCE.
EIMAC APPLICATION BULLETIN 5 PROCEDURE.

TUBE TYPE? 8938
CURVE NUMBER? 4435
DATE? OCTOBER 29 1974

PLATE-TO-G1 VOLTAGE=? 6100
DC BIAS VOLTAGE (NO-)=? 70
EB MIN VOLTAGE=? 500
EKM VOLTAGE=? 265

PLATE CURRENT POINTS.
A=? 18.0
B=? 17.5
C=? 15.5
D=? 11.5
E=? 6.60
F=? 2.00
G=? 0.001

GRID CURRENT POINTS.
A=? 1.40
B=? 0.70
C=? -0.05
D=? 0.025
E=? 0.025
F=? 0
G=? 0

DC PLATE CURRENT= 5.1750833 AMPERES
PEAK FUNDAMENTAL PLATE CURRENT= 8.5370833 AMPERES
POWER INPUT= 31568.008 WATTS
POWER OUTPUT= 23903.833 WATTS   ...   20,007W Amp. output (Useful)
PLATE DISSIPATION= 8795.3385 WATTS
PLATE LOAD RESISTANCE= 655.96174 OHMS
EFFICIENCY= 75.721702 PERCENT   ...     63.38% Amp. eff.
DC GRID CURRENT= .11666667 AMPERES
PEAK FUNDAMENTAL GRID CURRENT= .2270625 AMPERES
DRIVE POWER= 1161.2493 WATTS
INPUT IMPEDANCE= 30.236831 OHMS
GRID DISSIPATION= 22.138594 WATTS
POWER GAIN= 20.584583X OR  13.135421 DECIBELS ... 12.36 db Amp. gain

>
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FIGURE 9

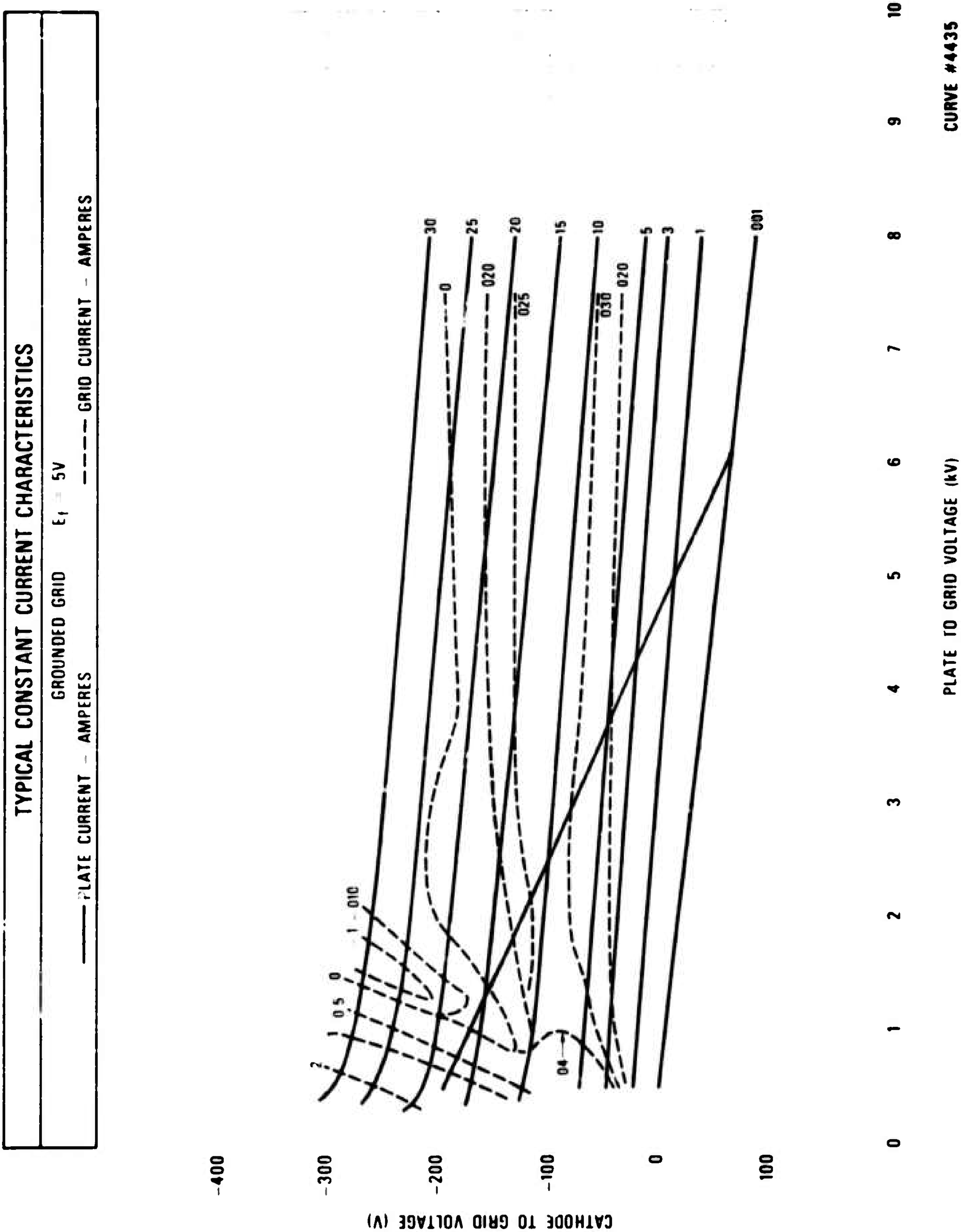

TYPICAL CONSTANT CURRENT CHARACTERISTICS
GROUNDED GRID
E_f = 5V
PLATE CURRENT – AMPERES
GRID CURRENT – AMPERES
PLATE TO GRID VOLTAGE (kV)
CATHODE TO GRID VOLTAGE (V)
CURVE #4435
-400
-300
-200
-100
0
100
0
1
2
3
4
5
6
7
8
9
10
30
25
20
15
10
5
3
1
.001
.020
.025
.030
.020
.010
.04

FIGURE 10

SUMMARY - CALCULATED AMPLIFIER PERFORMANCE CHARACTERISTICS

	CW			10 ms 10 cps Pulsed 0.1 duty				Pulsed 0.0625 duty			
Amp PO W	1251	1257	1250.3	1250.8	1249.7	1251	1250.6	1250.9	1250.9	1250.3	1250.1
Amp po W	--	--	--	12508	12497	12510	12506	20014	20014	20004	20001
BW(-1db) MHz	7.55	11	20	11	11	20	20	11	11	20	20
Amp Gain db	13.03	11.78	9.86	12.2	13.03	10.55	11.45	12.34	13.02	10.81	11.60
Amp Eff %	56.69	55.68	58.7	63.22	59.95	65.5	62.54	63.7	60.72	65.60	63.01
Pp W	773	836	877	557	651	638	709	540	626	630	692
Pg W	1.95	2.84	6.08	2.23	2.15	4.02	3.82	1.59	1.46	2.88	2.59
Ibo A	0.3	0.3	0.3	0.001	--	0.001	--	0.001	--	0.001	--
ibo a	--	--	--	--	0.8	--	1.0	--	0.7	--	1.0
Eb V	1920	1625	1205	4820	4820	3550	3550	6100	6100	4500	4500
Ec V	-5	-2	0	-52	-21	-39	-4	-68	35	-50	-12
Pd W	62.3	83.4	129	753	622	1103	897	1168	999	1660	1382
IB A	1.150	1.39	1.768	--	--	--	--	--	--	--	--
ib a	--	--	--	4.105	4.325	5.379	5.633	5.15	5.404	6.776	7.054
Ic ma	37	45	78	--	--	--	--	--	--	--	--
ic ma	--	--	--	142	143	209	209	133	126	200	188

FIGURE 11

AMPLIFIER DESIGN

A. The Output Circuit

The amplifier output circuit is double-tuned using sections of transmission line electrically one quarter wave long. The lines are tuned to resonance with sliding shorts. Coupling between the two cavities is capacitive and is variable to accommodate the bandwidth requirement at the various operating frequencies. The output (secondary) cavity is capacitive coupled to the output transmission line; the capacitance is made variable so that the cavity loaded Q can be held constant for different operating frequencies.

It was decided to use transmission line sections having a square outer conductor and round inner conductor for both primary and secondary cavities of the output circuit. The advantages of using this type of line instead of the round outer wall configuration are:

1. The mechanical arrangement used to couple two cavities is simpler.

2. Any desired line impedance is easily fabricated.

3. Production quantities of these are cheaper because some expensive machine work is eliminated.

4. Flat brass sheet is easier to obtain than the larger sizes of brass tubing.

5. A cavity requiring less space is obtained.

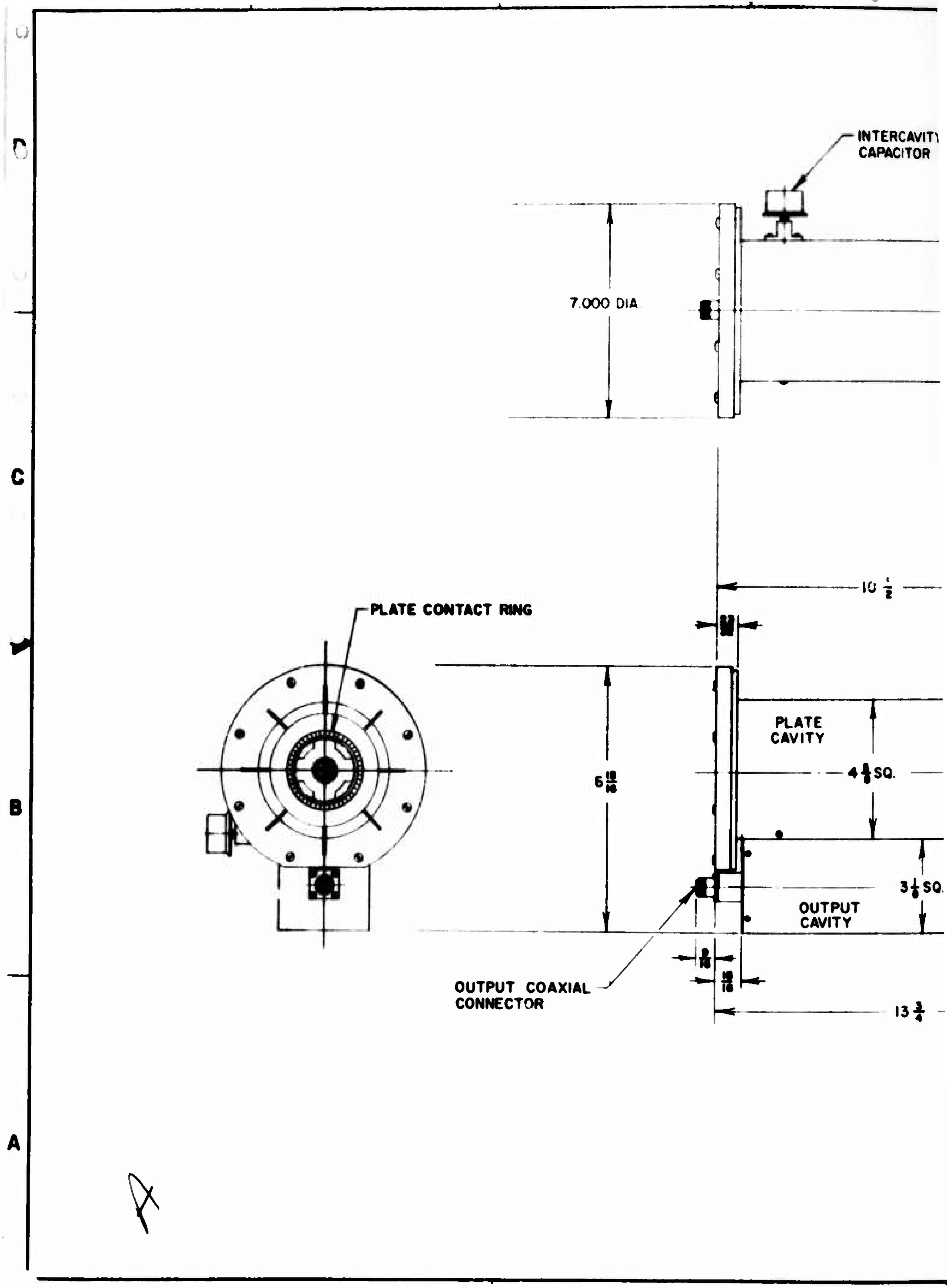
The tube output, or primary, cavity is a section of 46.3 ohm transmission line. The outer conductor is square and the inside walls are 4.525" apart. The inner conductor has an O.D, of 2.25 inches and also serves as the outer conductor of the tube input matching circuit.

The secondary circuit is a section of 56 ohm transmission line. The outer conductor is square with a wall spacing of 3.00 inches. The inner conductor is 1.25 inches O.D.

B. The Input Circuit

Since the amplifier tube is cathode driven the resistive input impedance at the cathode is calculated to lie between 33.6 and 30.2 ohms, the exact value depends upon the power level at which it is operating. Therefore the input circuit was designed to transform 32 ohms at the tube to the desired 50 ohms at the coax input connector.

The input circuit is a length of 50 ohm coaxial line approximately 11 inches long. The inner conductor connects to the tube cathode. The outer conductor connects to the grid and is also the inner conductor of the plate circuit. A one inch thick ring contacts the inner conductor and can be moved on that conductor. The outer surface of the ring is approximately 0.035 inch from the outer conductor and this forms the input capacitor of the pi network. The output capacitor of the pi is the cathode-to-grid capacitance of the tube. The input circuit is tuned to resonance by moving the ring on the inner conductor, in effect changing the inductance between the capacitors to establish resonance. A layout drawing of the cavity is shown in Figure 12. Photographs showing the amplifier cavity and tube are presented in Figures 13, 14 and 15.


INTERCAVITY CAPACITOR
7.000 DIA
PLATE CONTACT RING
10 1/2
PLATE CAVITY
OUTPUT CAVITY
OUTPUT COAXIAL CONNECTOR
13 3/4
D
C
B
A

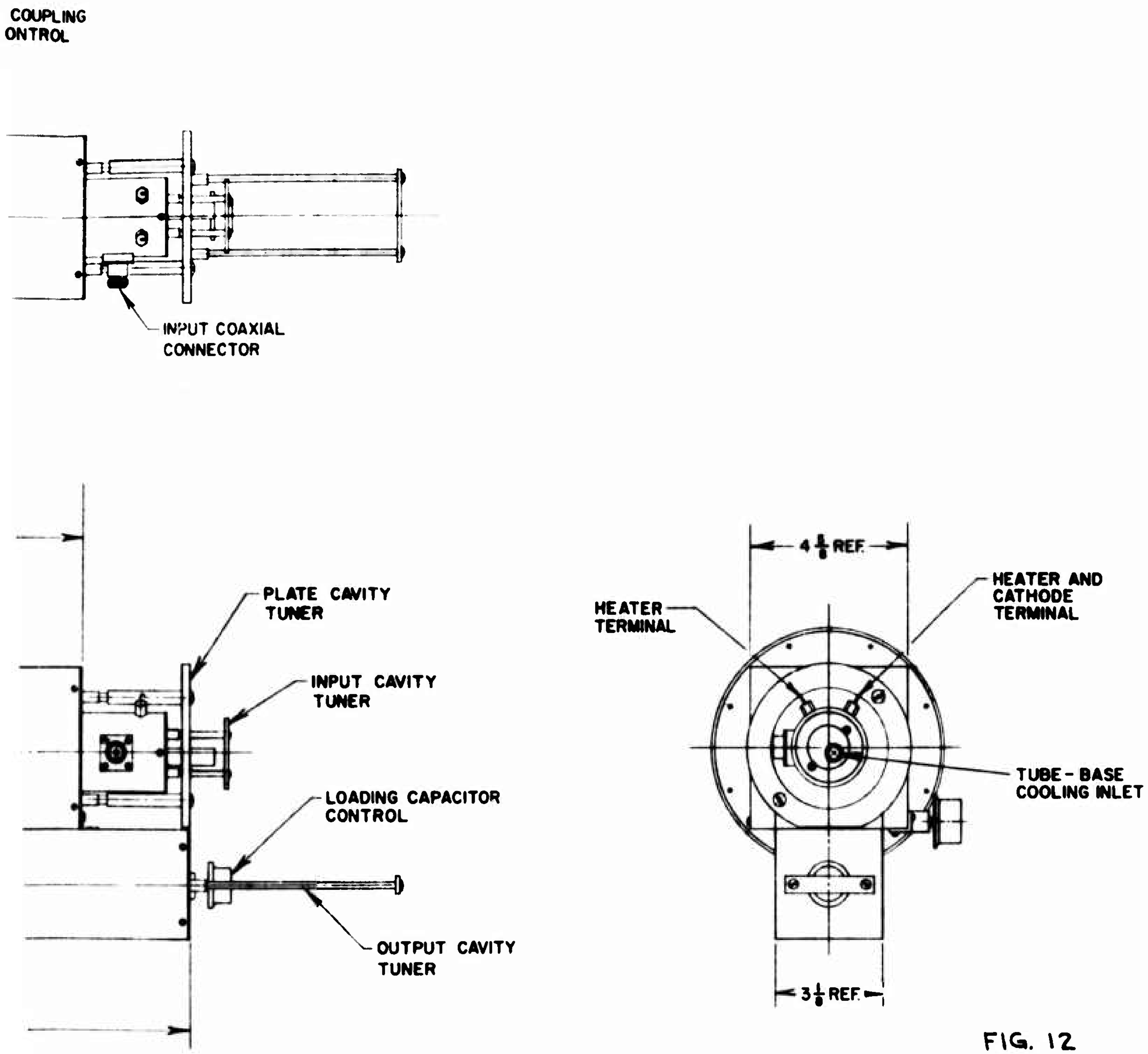


FIG. 12

Page 20

REVISIONS

ZONE	LTR	DESCRIPTION	ECO	DATE	BY APPD

QTY	PART NUMBER	DESCRIPTION	CODE IDENT	ITEM

LIST OF MATERIALS

QTY	USED ON	NEXT ASSY

APPLICATION

UNLESS OTHERWISE SPECIFIED

DIMENSIONS IN INCHES
FRACTIONS ±1/64
DEC ±.005, ANGLES ±1

EIMAC GEN MFG SPEC PSMS 82 APPLIES

MATERIAL

SPEC NO

FINISH

CONTR NO

DR JD — DATE 2 OCT 74

CH

APPD

DESIGN ACTIVITY APPD

APPROVED

DIV — EIMAC, Division of Varian

225-400MHz BROADBAND POWER AMPLIFIER CAVITY

SIZE D — CODE IDENT — DWG NO 169021 — REV

SCALE HALF — SHEET ___ OF ___

FIGURE 13

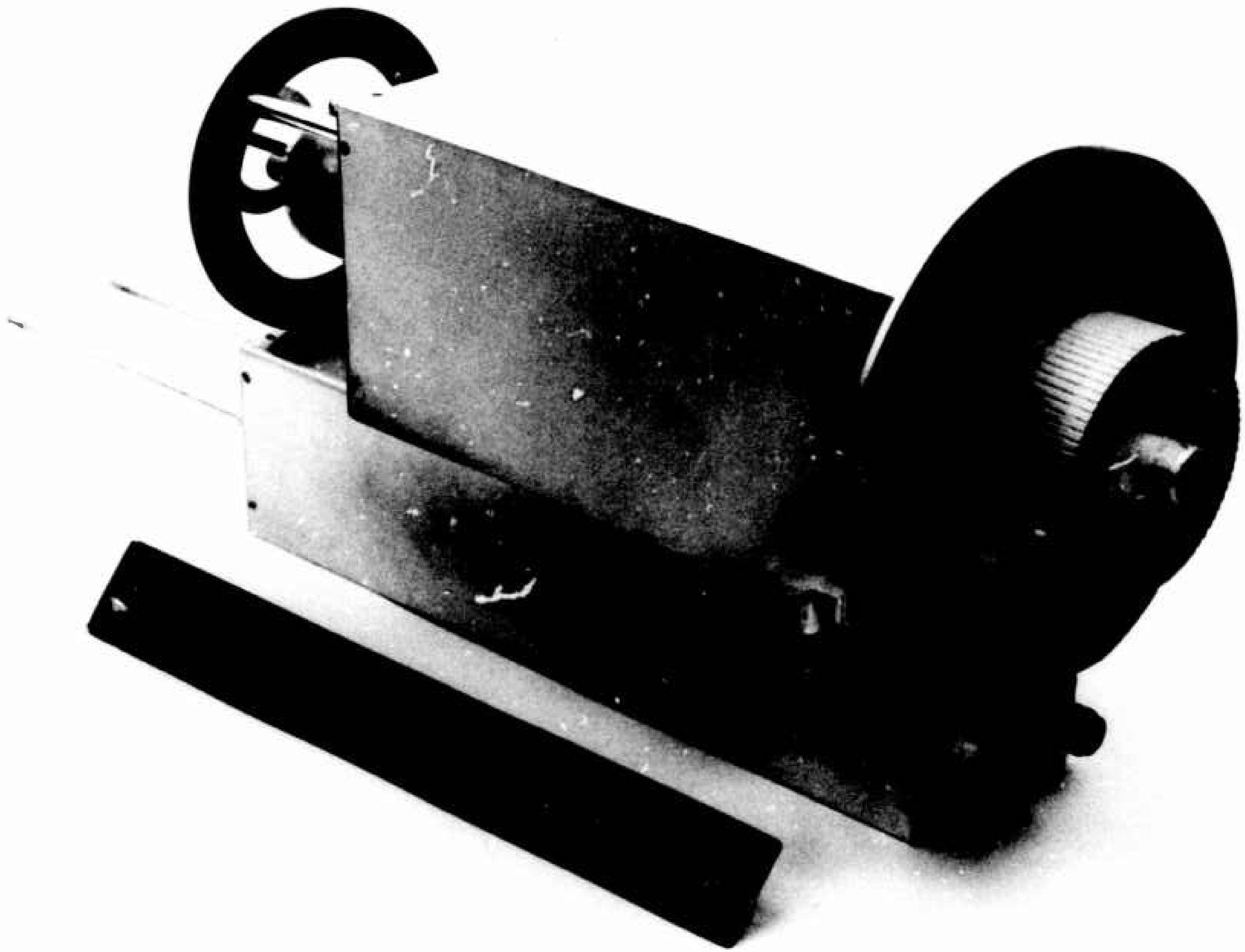


FIGURE 14

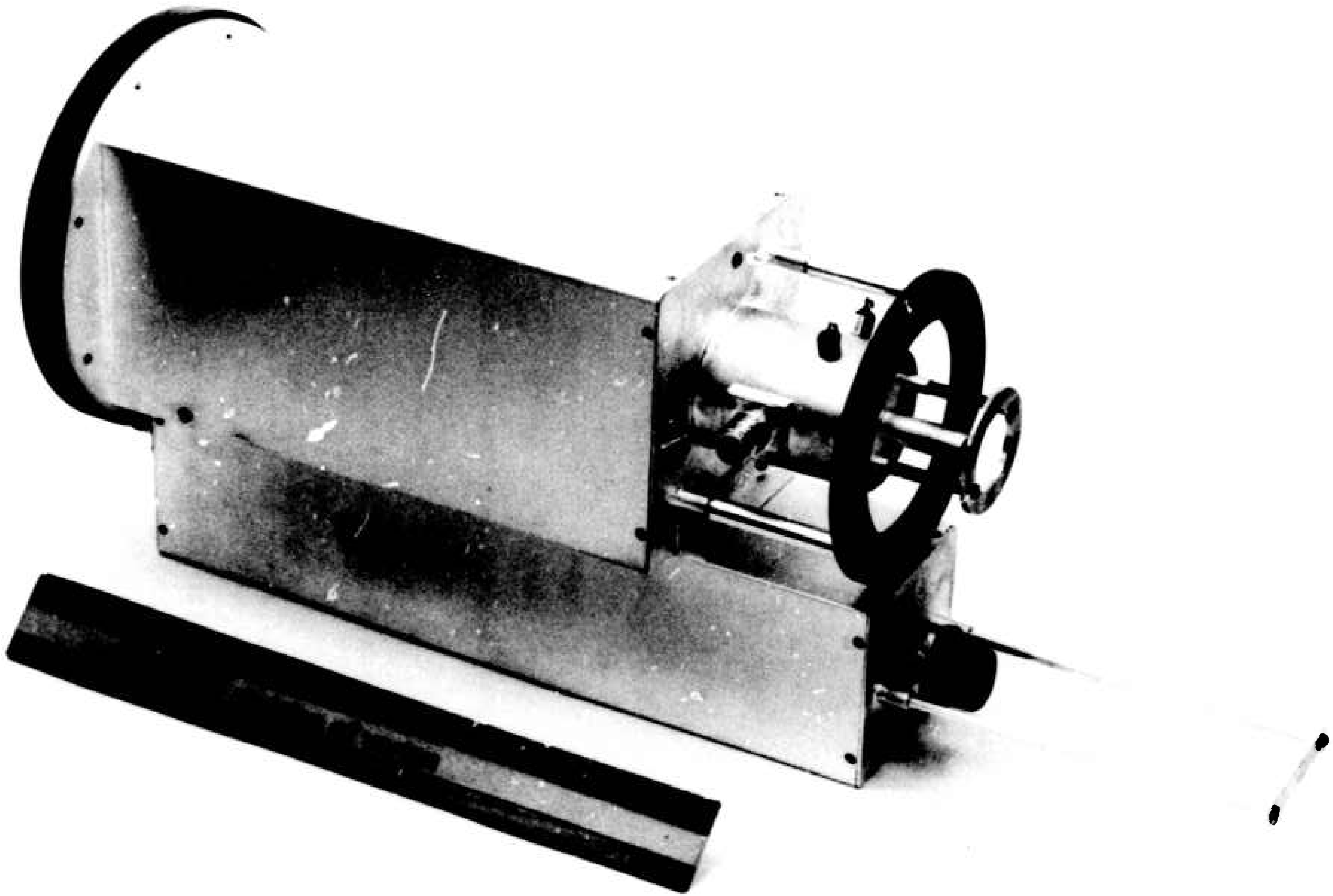


FIGURE 15

AMPLIFIER PERFORMANCE

CW Operation

The operating conditions and typical test results for CW are shown in Table II. Amplifier adjustments were made using the test set-up shown in Figure 16; Block Diagram of Test Set-up - CW. Test data were taken while operatiang with the setup shown in Figure 17; Block Diagram of Test Set-up - Swept Band Width Measurement.

Operating conditions were as follows:

Eb = 1625V, Ib = 1.37A, Ec = -3V, Ibo = 0.30A

Test results were as follows:

TABLE II

Tube S/N	Freq. MHz	Ef Volts	Ic Ma	BW(-1db) MHz	PO Watts	Pd Watts	Eff. %	Gain db
B4C-79	390	3.5	-5	12.22	1068	78.5	48	11.33
B4C-79	300	4.0	-5	11.94	1200	75	53.9	12.0
B4C-79	230	4.0	+100	11.17	1395	96.2	62.6	11.6
G4D-89	390	3.5	-37	12.27	1216	70.4	54.6	12.37

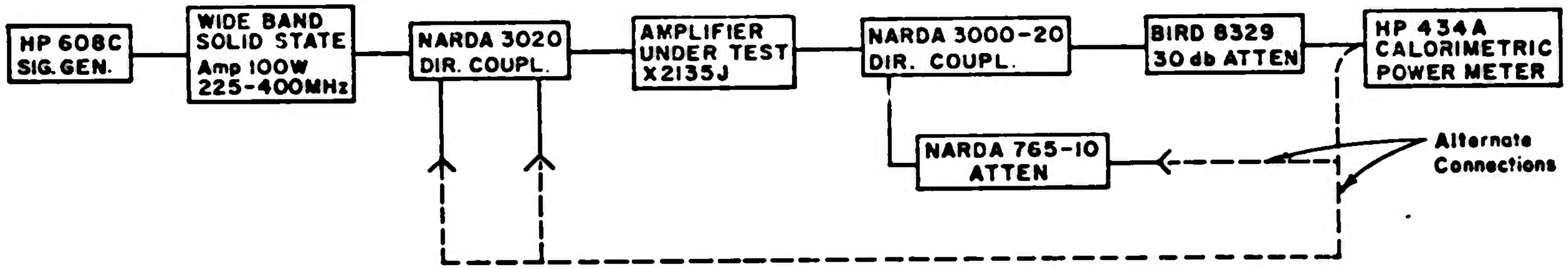
PULSE OPERATION

Operating conditions and typical test results for pulse operation are shown in Table III. Amplifier adjustments were made using the test setup in Figure 17; Block Diagram of Test Setup - Swept Bandwidth Measurement. Test data were taken while operating with the test setup shown in Figure 18; Block Diagram of Test Setup - High Power Pulse.

Operating conditions were as follows:

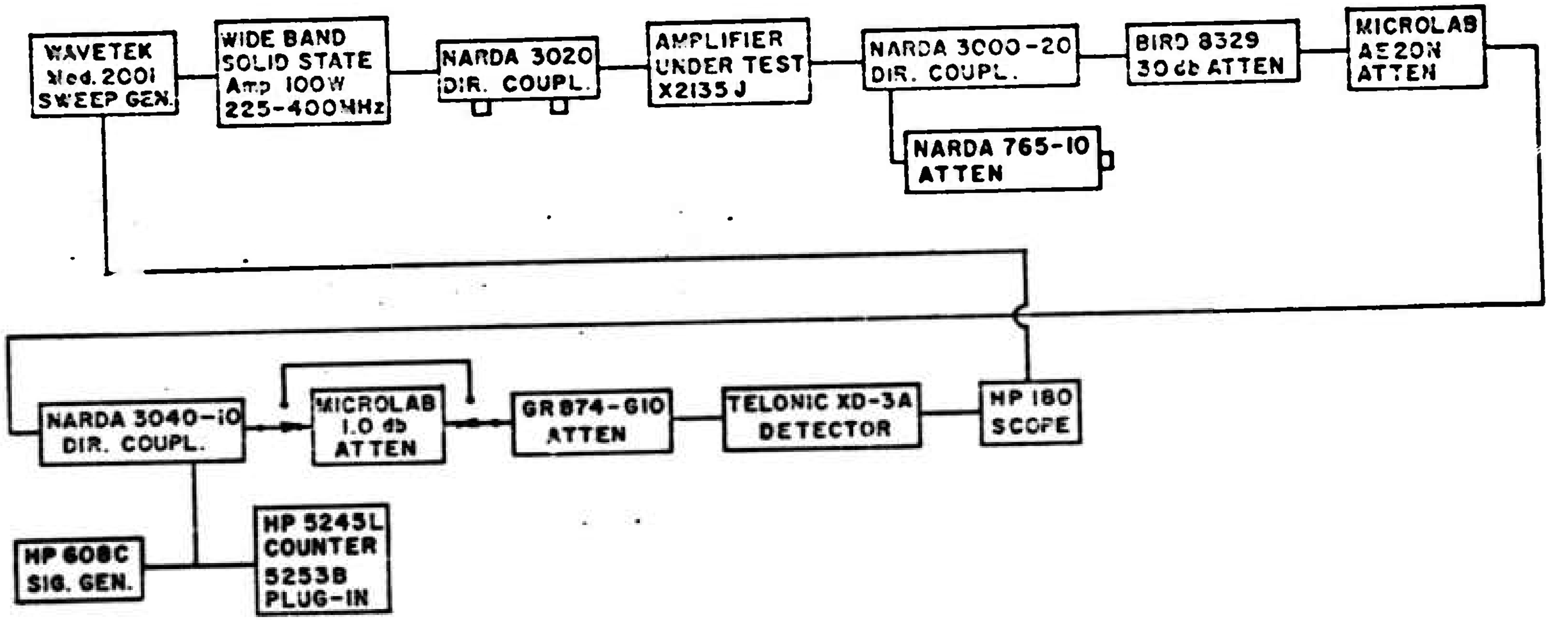
Eb = 4850V, Ec = 50V, Ibo = 1ma, Ef = 5.0V
Duty = 10%, Pulse Length = 10 ms, Rep.rate - 10 pps

These pulse opearting conditions were selected because they represent the most severe pulse conditions listed in the Design Objectives, Table 1.



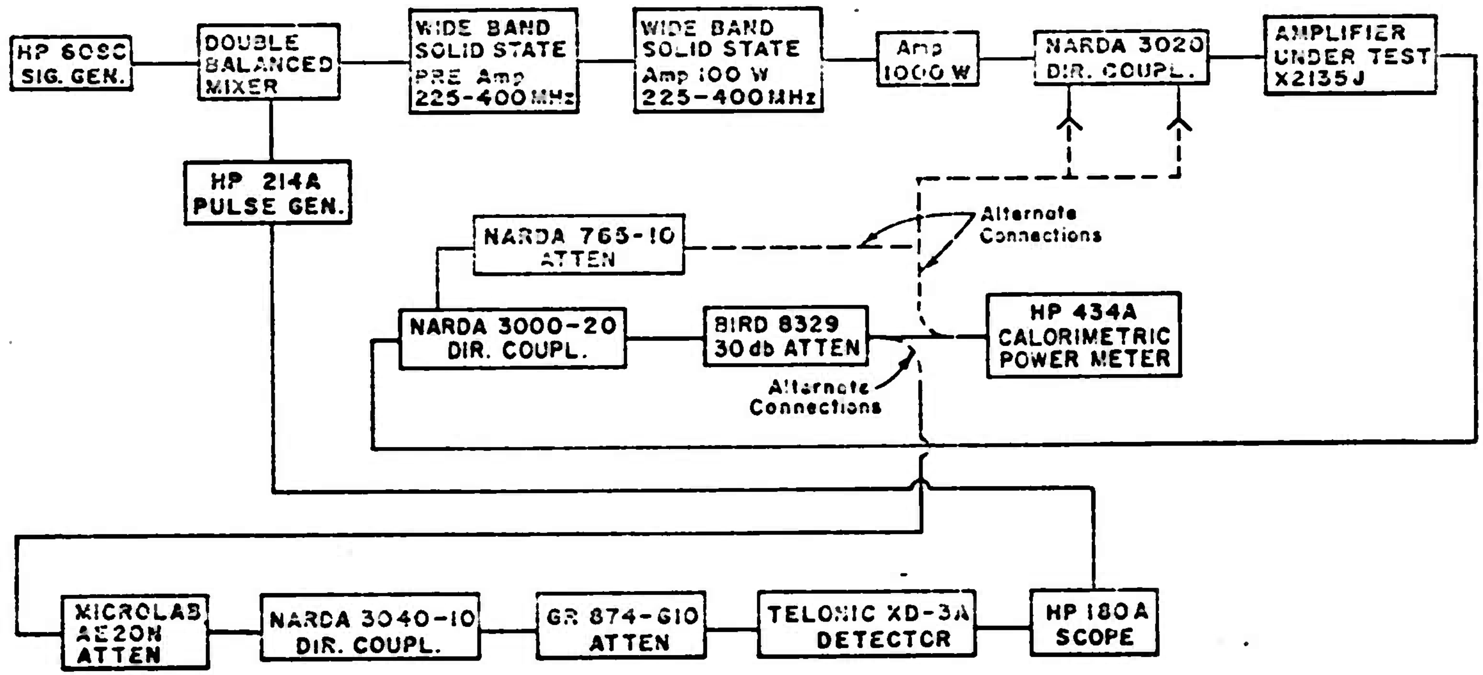
BLOCK DIAGRAM OF TEST SET UP – CW

FIGURE 16



BLOCK DIAGRAM OF TEST SET UP — SWEPT BAND WIDTH MEASUREMENT

FIGURE 17



BLOCK DIAGRAM OF TEST SET-UP — HIGH POWER PULSE

FIGURE 18

Test results were as follows:

TABLE III

Tube S/N	Freq. MHz	ib a	ic ma	BW(-1db) MHz	PO kw	Pd W	Eff. %	Gain db
G4D-91	390	4	+100	12.29	12.12	659	67.7	13.36
G4D-91	300	4.18	+350	11.92	12.99	747	64	12.36
G4D-91	230	3.7	+600	11.30	12.68	799	70	12.0
G4D-92	300	4.5	+400	12.03	12.51	951	61.4	11.2

INTERMODULATION DISTORTION 400 MHz TESTS

The operating conditions and test results for two-tone linearity measurements made at a 400 MHz center frequency are shown in Table IV. Amplifier adjustments were made by using the test set-up as shown in Figure 17; Block Diagram of Test Set-up - Swept Band Width Measurement. 400 MHz test data were taken while operating with the test set-up shown in Figure 19; Block Diagram of Test Set-up - Two-tone Linearity Test.

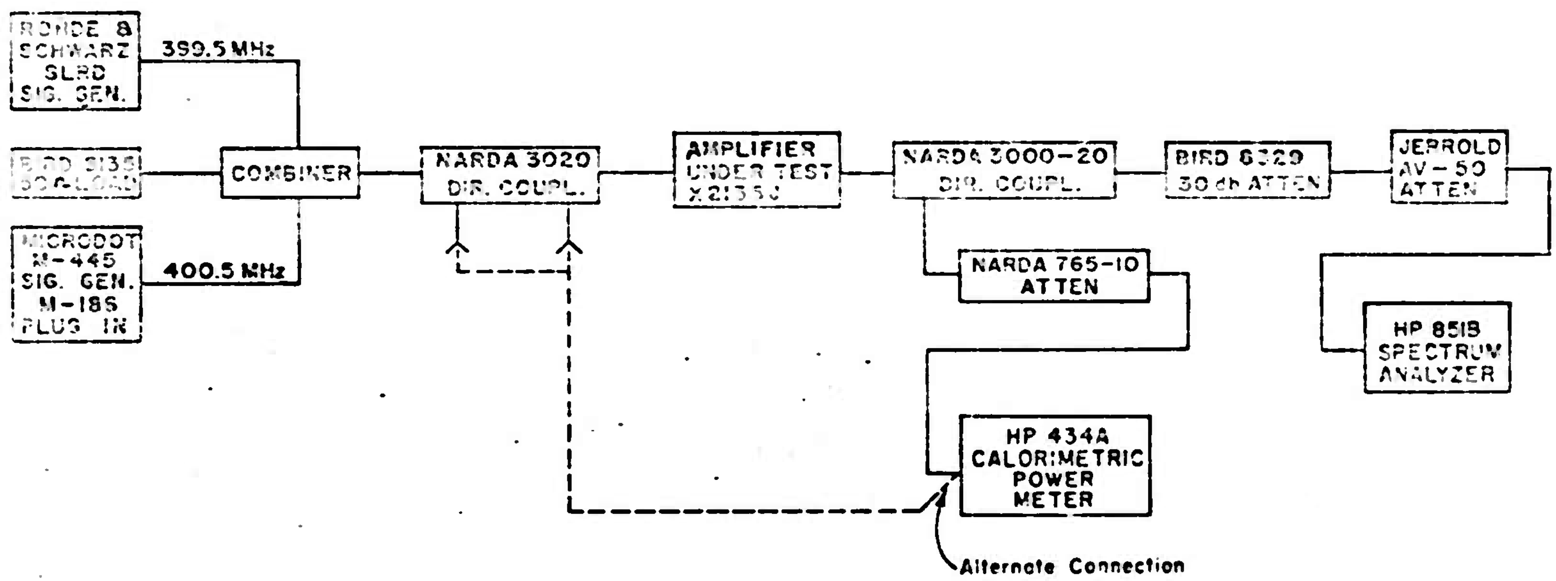
Operating conditions were as follows:

Eb = 1625V, BW(-1db) = 12.15 MHz

Test results were as follows:

TABLE IV

PO W-PEP	Pd W-PEP	Ec V	Ibo Ma	Ib Ma	Ic Ma	3rds L	3rds H	5ths L	5ths H	7ths L	7ths H	9ths L	9ths H
558	33.8	-10	100	530	+1	-20	-22	-28	-35	-38	-45	-46	-55
624	32.2	-5	200	610	+1	-19	-21	-32	-34	-43	-52	-50	-55



BLOCK DIAGRAM OF TEST SET-UP — TWO TONE LINEARITY TEST

FIGURE 19

INTERMODULATION DISTORTION 2 MHz TESTS

The operating conditions and test results for two-tone linearity measurements made at 2 MHz are shown in Table V. The data were taken using the EIMAC laboratory linearity test equipment.

The load impedance used was 650 ohms, the same that was calculated to exist for the 400 MHz linearity tests summarized by Table IV. The plate voltage was 1625V.

Test results were as follows:

TABLE V

PO	Ec	Ibo	Ib	Ic	Distortion Products			
W-PEP	V	Ma	Ma	Ma	3rd	5th	7th	9th
688	-10.7	100	625	7	29	38	44	48
662	-6.5	200	650	5	33	44	50	56

TRIODE AMPLIFIER TUBE DEVELOPMENT & EVALUATION

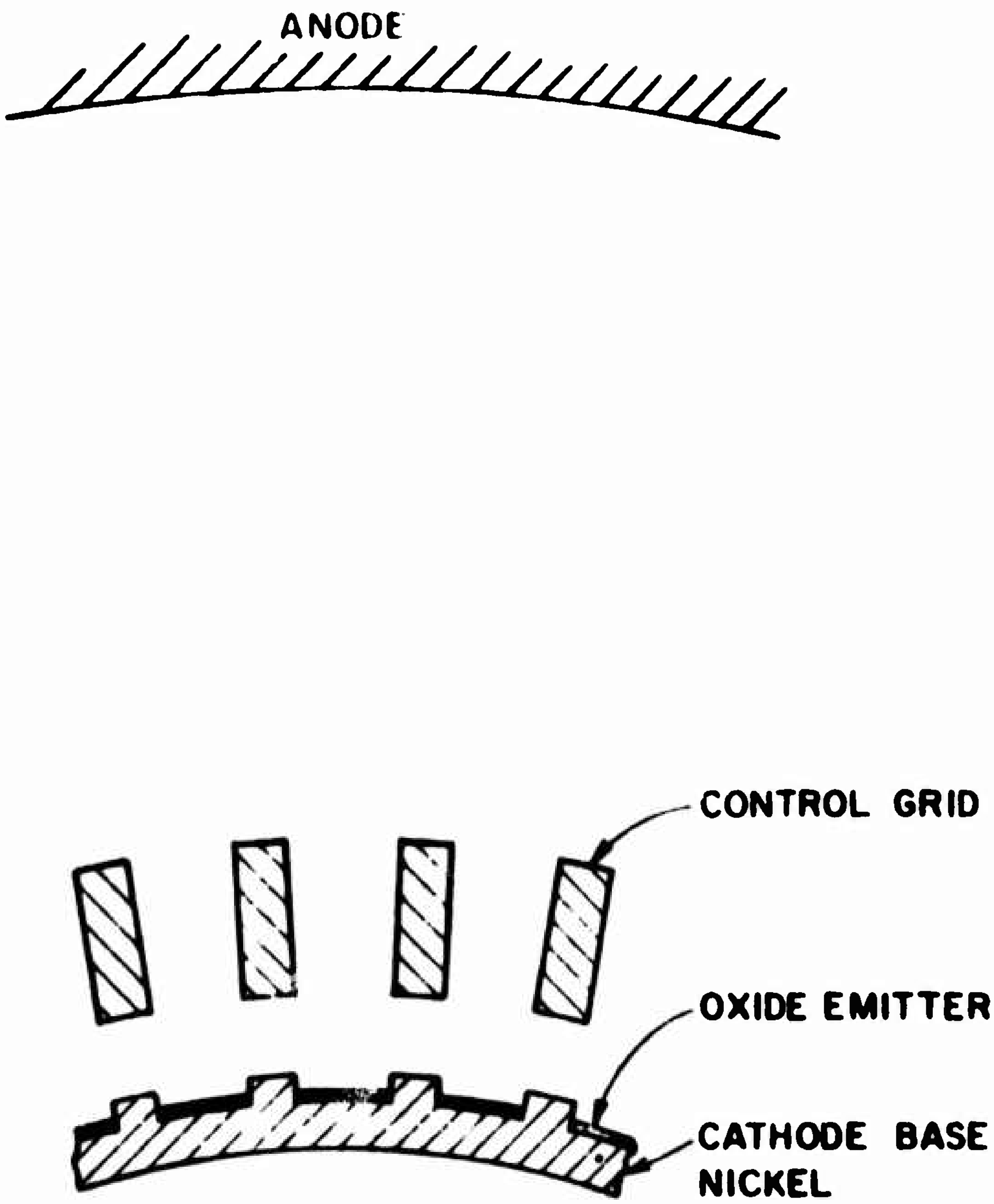
Triode - Type 8938 Prototype

This tube was selected for evaluation and further development in the linear power amplifier, in view of the successful operation of this type in amplifiers at frequencies to 600 MHz and in oscillators at mugh higher frequencies.

The EIMAC 8938 is a coaxial based triode electron tube for zero-bias or low-bias operation at high plate voltages. The tube has a low ratio of grid-to-plate current even at high positive grid voltages. This is accomplished by use of a segmented-emitter cathode, which, in conjunction with a deep vane control grid, forms ribbon-shaped electron beams that pass between the control grid vanes, with very little interception. This triode design has high gain and high efficiency with very low feedback capacitance from anode to cathode in cathode-driven (grounded grid) amplifiers. The grid-to-plate amplification factor is great enough (200) to eliminate the requirement for bias voltage in most amplifiers so that only one power supply (the plate supply) is usually required; yet the grid current at peak positive grid-to-cathode voltage can be made to be very low. Thus the grid dissipation power will be low and high power output can be obtained.

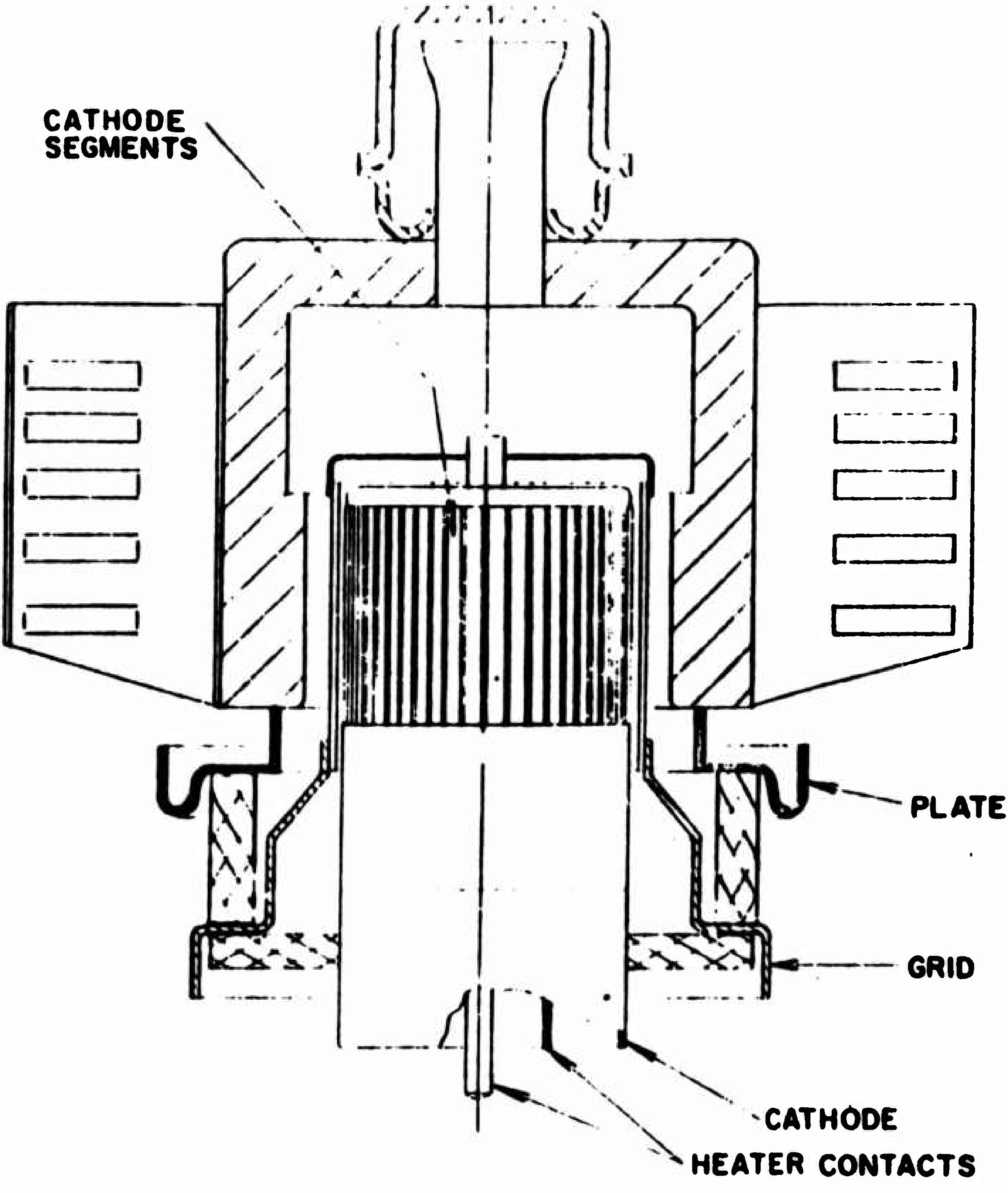
The electrical characteristics of this triode are obtained by the unique construction of the cathode and control grid and by the geometrical relationship between the control grid and cathode. The cathode is a metal cylinder with shallow, longitudinal grooves cut into the outer surface and equally spaced around the periphery. These grooves are partially filled with the thermionic electron emitter "oxide cathode mix". The grid is a cylindrical array of metal bars approximately rectangular in section with the narrow side facing the non-emitting metal surface ("land") which lies between the emitting grooves. The segmented cathode and aligned bar grid shown in Figure 20 provides excellent electron beam focusing and minimizes grid current interception.

Figure 21 shows an axial section of the 8938. The electrodes and electrode supports are short coaxial cylinders and cones. They are arranged for minimum capacitance and inductance, consistent with provisions for shielding of insulator surfaces from cathode sublimation products, insulation of voltage, and thermal isolation of the cathode from the cool



TRANSVERSE SECTION OF 8938 TRIODE
SHOWING SEGMENTED CATHODE

FIGURE 20



SECTION OF 8938 TRIODE

FIGURE 21

envelope of the tube.

An examination of the constant current plate characteristics as compared to a typical set of tetrode curves will show a remarkable similarity. The constant current lines are almost horizontal indicating very high plate resistance typical of a tetrode. In the UHF region, the grounded-grid 8938 provides roughly the same gain as a tetrode with far less circuit complexity and fewer power supplies.

Experimental Program for Thermal Management of Triode Amplifier Tubes.

RF Conductivity of Electrodes

An analysis of the conductivity of the electrode supports of the type 8938 triode was made. This analysis took into account the effect of frequency on the skin resistance of metals and coatings used.

The grid support of the type 8938 triode is made of nickel and the sealing ring and the plate contact flange are made of Kovar alloy. Nickel has a moderate resistance and has an initial permeability (μ_i) of 100 to 200. Kovar has a high specific resistance and a high initial permeability, greater than 1000 to room temperature. However, the Kovar parts are external and are normally silver plated and brazed to the ceramic insulators with copper-silver eutectic alloy which is highly conductive but which, because it is then, does not increase the thermal conductivity of the Kovar. The calculated skin resistance of the grid support of the 8938 was 0.017 ohms. When the load current and the displacement currents flow through this resistance, the dissipation in the support will be about 7 watts. This additional power which must be removed by conduction to the external contact flange and thence to the cooling air reduces the grid dissipation capability of the tube. The resistance of the surface of the grid support which faces the cathode gives rise to extra power consumption and negative feedback in the input circuit.

The X2135J, 8938 with High Conductivity Electrodes

These tubes (type X2135J) were made with copper-clad seals, plate contact flanges, and grid supports. The thickness of the copper was 0.002 inches, each surface.

The rf resistance of the grid support was thereby reduced from 0.017 ohms (8938) to less than 0.004 ohms, each side. Also, the thermal conductivity of the support and the sealing rings and the plate contact flange was increased by an order of magnitude. These two effects: decrease in rf resistance and an increase in thermal conductivity, permitted operation at 5 to 10 watts greater grid dissipation and improved power gain and efficiency of the tube.

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3. "Drive-point Impedance of Lumped-Constant Output Networks for Power Amplifiers, W. V. Parker. Final Report Contract DA36-039-AMC-03203 (E), Feb. 25, 1965.